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DIRECT POWER CONTROL FOR A PHOTOVOLTAIC CONVERSION CHAIN CONNECTED TO A GRID

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Key words: Solar energy, Maximum power point tracking (MPPT), Fuzzy logic control (FLC), Direct power control, Electrical grid.

Solar energy represents the future of the world in matter of clean energy. Its use and mainly the photo voltaic (PV), for different applications including grid connected, are well suited to most of the rural areas due to the lack of electrification. In this paper we proposed a strategy for optimizing the performance of a grid-connected photovoltaic system. For this, we opted for an MPPT control method based on the fuzzy logic controller. The control and improving of the performance of a voltage source inverter for grid connected photovoltaic systems, we proposed to use a modern technique which is called direct power control. Simulations of the proposed approach give interesting results compared to the existing control strategies in this field. The model of the proposed system is simulated by MATLAB / Simulink.

1. INTRODUCTION

Solar energy is an excellent source, it is clean and promising [1]. It also acclimatizes well with multiple systems. In recent years the uses of solar installations with electric networks are very common especially in remote places. To extract the maximum of power that can be generated from the photovoltaic panel which has finite internal impedance, the inverter and PV panel impedances must be equal as it is viewed in its output. To solve this problem the establishment of an adapter is required. This adapter is a dc-dc converter and a maximum power point control.

There are several methods to obtain the maximum power of the photovoltaic generator [2, 3]. The most famous ones are: perturbation and observation (P & O) [4], incremental conductance [5], short circuit method [6], of the open-circuit voltage [7] and the feedback methods of power [8]. During the day, the solar density is variable; most of these algorithms fail to track the maximum power point regularly. For this reason, the methods based on “artificial intelligence” are used. Among which the authors [9, 10] have suggested MPPT algorithm based on artificial neural networks. The author [10] suggested genetic algorithms, and [9, 11] have used fuzzy logic to obtain the optimum power point. The extracted power using the photovoltaic generator is transferred to the inverter through the intermediation of a dc bus.

In the last few years, technology of electric grid control is improving, thanks to the evolution of the inverter control technology. The direct power control (DPC) is a modern technique proposed by [12] to ensure control decouples the active and reactive power control with internal current loop. The principle of this technique is inspired by the direct torque control for induction machines. The main theme of this study is based on two principles: a technique of intelligent control that is based on fuzzy logic to track the maximum power point of photovoltaic generator (PVG) controller and to improve energy conversion efficiency.

The DPC control used to improve the performance of active and reactive power.

In the first section we presented the mathematical models of the PV array and boost converter. The second section we presented the used method of MPPT control. The direct power controller principle is demonstrated in Section 3. The 4th section presented the proposed system. Finally in Section 5, the simulation and discussion of the results are presented.

2. PHOTOVOLTAIC GENERATOR

The PVG model used in this study consists of a generator current, a single diode, a series and parallel resistances [13]. The output current of the solar cell is given by:

$$I_{\mathrm{PV}} = I_{\mathrm{ph}} - I_{\mathrm{d}}\left[\exp\left(\frac{\mathrm{e}}{k_B TA} V_{\mathrm{PV}}\right) - 1\right], \quad (1)$$

$$I_{\mathrm{ph}} = S\left(I_{\mathrm{scr}} + k_{\mathrm{i}}\left(T - T_{\mathrm{r}}\right)\right), \quad (2)$$

$$I_{\mathrm{d}} = I_{\mathrm{rr}}\left(\frac{T}{T_{\mathrm{r}}}\right)^3 \exp\left(\frac{\mathrm{e}.E_{\mathrm{g}}}{k_{\mathrm{B}} QA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right), \quad (3)$$

where:

I_{PV}, V_{PV} – the output current and voltage [A, V],
I_{ph} – light generated current,
I_{d} – PV saturation current,
I_{rr} – saturation current at T_{r},
I_{scr} – short circuit current at reference condition,
T_{r} – reference temperature,
T – cell temperature [K],
S – solar irradiance [W/m^2],
k_{B} – the Boltzmann’s constant,
K_{i} – short-circuit temperature coefficient,
Q – total electron charge,
e – charge of an electron,
E_{g} – band-gap energy of the material,
A – ideality factor.

3. DC-DC CONVERTER

The dc-dc boost converter can be used to increase the PV voltage at the input of the three-phase voltage source inverter and tracking of the maximum power point. Figure 1 shows circuit the boost converter [13].

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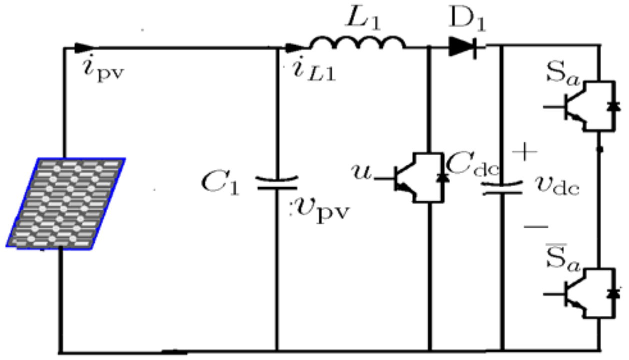

Fig. 1 – The boost converter.

The output voltage of the boost converter is expressed by the following equations: [13]

$$\frac{v_{dc}}{v_{pv}} = \frac{1}{1-u}, \tag{4}$$

where:

v_{pv} – input voltage of the boost converter,
v_{dc} – output voltage of the boost converter,
U – duty cycle.

4. MPPT CONTROLLER OF PV SYSTEMS USING FUZZY LOGIC CONTROLLER (FLC)

In general, a fuzzy controller is divided on the following three blocks [14]: the fuzzification to convert real variables to fuzzy ones. Then the inference where these variables are compared with predefined sets to determine appropriate response and finally defuzzification, to convert the subset fuzzification in values [14, 15]. The basic structure of our fuzzy controller is shown in Fig. 2 [14, 16].

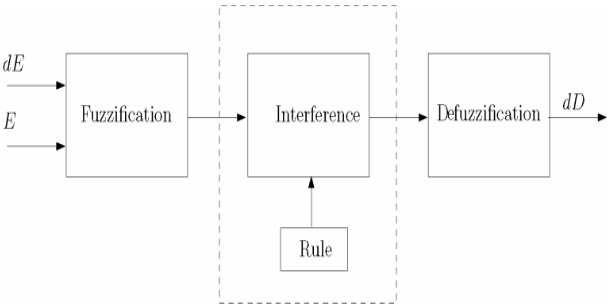

Fig. 2 –Basic structure of fuzzy controller.

In what follows, we will detail the steps achievements of fuzzy controller which comprises three blocks next:

FUZZIFICATION

The used controller consists of two input variables: error (E) and the change of the error (dE) are expressed as follows:

$$E_k = \frac{P_{pv_k} - P_{pv_{k-1}}}{v_{pv_k} - v_{pv_{k-1}}}, \tag{5}$$

$$dE_k = E_k - E_{k-1}, \tag{6}$$

where P_{pv} and v_{pv} are respectively the power and the voltage of PV panel at sampling instants kT_s.

Five linguistic variables are adopted for each of the input/output variables, where NB (negative big), and NS (negative small), Z (zero), PS (positive small) and PB (positive big). The five basic fuzzy subsets for input and output variables are presented in Fig. 3.

FUZZY INFERENCE

In the literature, several composition methods are proposed. In this study, we chose to use of the method Mamdani fuzzy inference.

Table 1

Table of fuzzy rules

E \ *dE*	NB	NS	Z	PS	PB
NB	Z	Z	PB	PB	PB
NS	Z	Z	PS	PS	PS
Z	PS	Z	Z	Z	NS
PS	NS	NS	NS	Z	Z
PB	NB	NB	NB	Z	Z

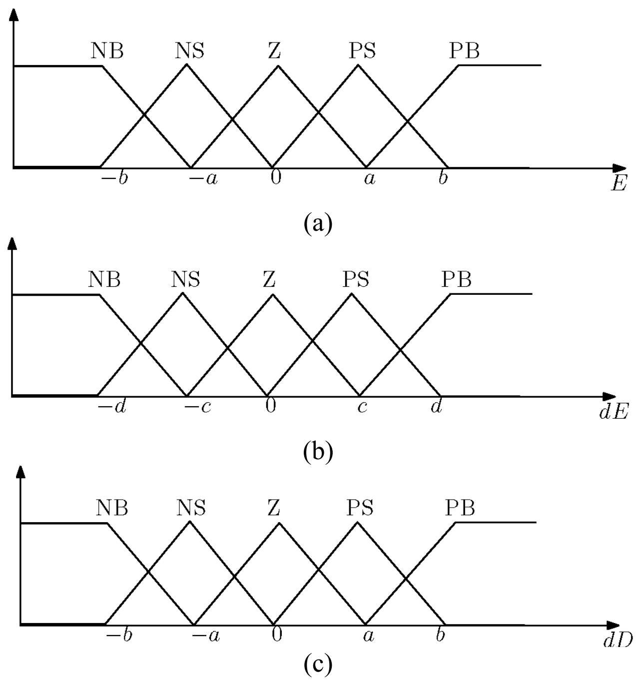

Fig. 3 – Definitions and membership functions of: a) the 1st input variable (E); b) the 2nd input variable (ΔE); c) the output variable (dD).

DEFUZZIFICATION

The defuzzification transforms this fuzzy output into a numeric value. The most used defuzzification method is the center of gravity method. Accordingly, the change of the duty cycle (dD) is determined by following equation:

$$\mathrm{d}D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)}, \tag{7}$$

where μ is membership function.

Finally, the duty cycle (D) is obtained by:

$$D_k = D_{k-1} + \mathrm{d}D_k. \tag{8}$$

5. **DIRECT POWER CONTROL**

Figure 4 presented the diagram of direct power control. Two types of sensors are required for measured the voltage $e_{abc}= [e_a, e_b, e_c]^T$ and the current line $i_{abc}= [i_a, i_b, i_c]^T$ of the electrical grid. The value of voltage and current allow estimating the reactive and active powers by equation (9).

$$\begin{cases} P = i_\alpha . e_\alpha + i_\beta . e_\beta \\ q = i_\alpha . e_\beta - i_\beta . e_\alpha \end{cases}, \tag{9}$$

where P and q is the active and reactive power of electrical grid.

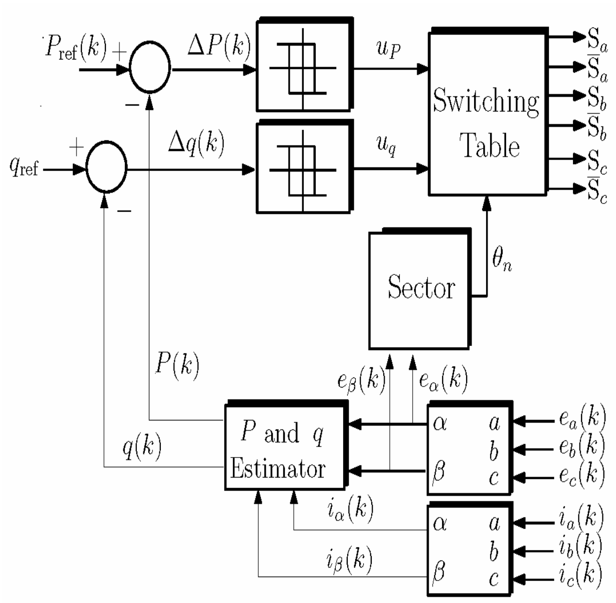

Fig. 4 – The diagram of direct power.

By using Concordia transformation, the voltage $e_{\alpha\beta}= [e_\alpha, e_\beta]^T$ in the α-β frame are given by the following equations:

$$e_{\alpha\beta} = \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}. \tag{10}$$

Similarly, the current $i_{\alpha\beta} = [i_\alpha, i_\beta]^T$ in the α-β frame can be expressed as follows:

$$i_{\alpha\beta} = \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}, \tag{11}$$

where $e_{abc}= [e_a, e_b, e_c]^T$ is the voltage and $i_{abc}= [i_a, i_b, i_c]^T$ is the current line of the electrical grid.

The reference value of active P^* and reactive q^* power are given directly as constant and compared with the value estimate of P and q. the results of this comparison presented input of the hysteresis regulator, the output of this regulators is digitized variable u_p and u_q follows [17]:

$$\begin{aligned} u_p &= 1 \ \text{ if } \ P^* - P \geq h_p \quad u_p = 0 \ \text{ if } \ P^* - P \leq -h_p \\ u_q &= 1 \ \text{ if } \ q^* - q \geq h_p \quad u_q = 0 \ \text{ if } \ q^* - q \leq -h_p \end{aligned} \tag{12}$$

The line voltage vectors position (θ_n) determined by following equation:

$$\theta_n = \text{arctg}\left({e_\beta}/{e_\alpha} \right). \tag{13}$$

The switching table has three inputs are: the digitized variable u_p, u_q and θ_n. The output is the switching state S_a, S_b and S_c of the inverter [17]. Bouafia *et al.* [18] proposed new switching table for eliminated disadvantage of classical DPC. This method applied for monitor to three phase PWM rectifiers. In this paper we used the same switching table to monitor to an inverter connected to the grid. The proposed new switching table as described in detail in [18].

Table 2

The proposed switching table for DPC

S_p	S_q	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}
1	0	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5
	1	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3
0	0	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6
	1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1

V_1(100), V_2(110), V_3(010), V_4(011), V_5(001), V_6(101), V_0(000), V_7(111)

6. **DESCRIPTION OF THE CONTROL SYSTEM:**

A typical circuit topology of the present work as shown in Fig. 5 it consists of two major parts:

– fuzzy logic MPPT controller, this is used for the power coming from PVG;

– direct power controller; in order to improve the performance of the active and reactive power.

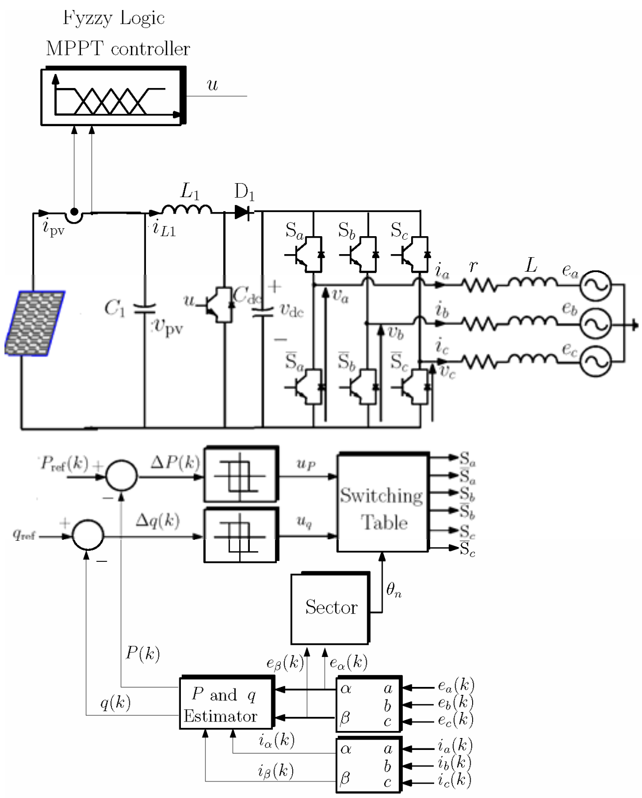

Fig. 5 – Block diagram of a grid-connected photovoltaic power system.

7. SIMULATION RESULTS

The simulation results of the proposed system were implemented using Matlab / Simulink. In this case, we take the values of the standard conditions: 25 °C of temperature and solar radiation is1 000 W/m^2.

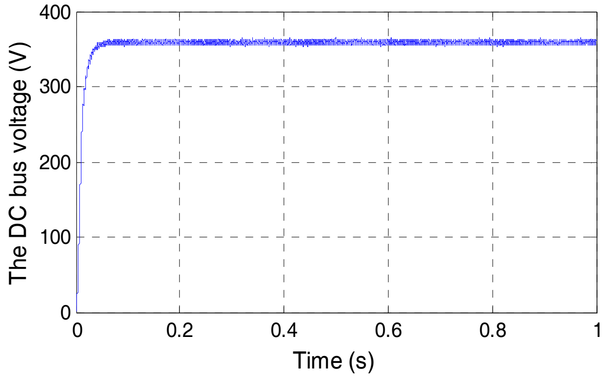

Fig. 6 – The dc bus voltage.

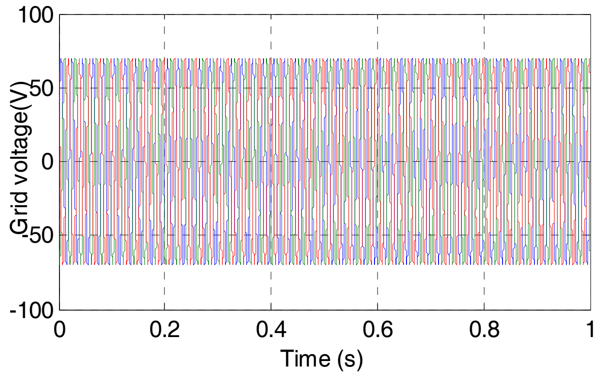

Fig. 7 – Phase voltage.

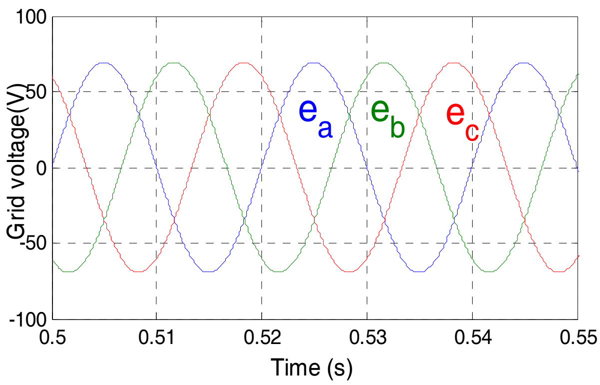

Fig. 8 – Zoom of phase voltage.

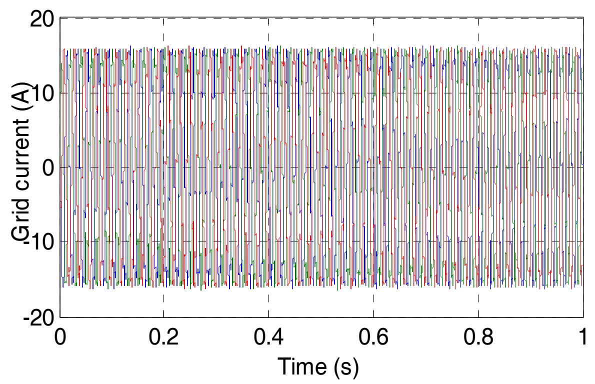

Fig. 9 – Phase current.

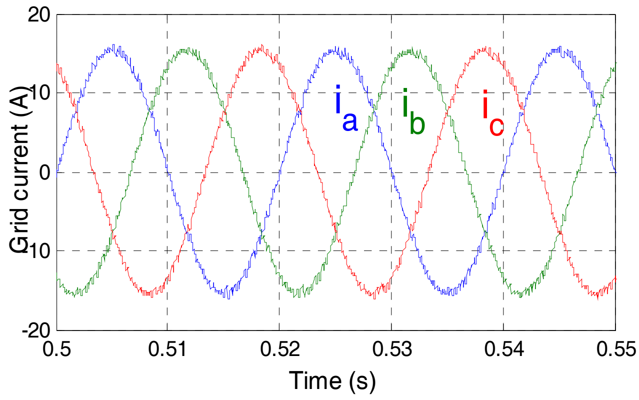

Fig. 10 – Zoom of phase current.

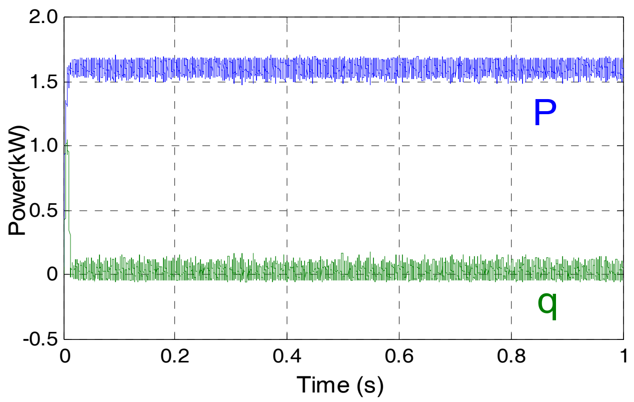

Fig. 11 – Active and reactive grid power.

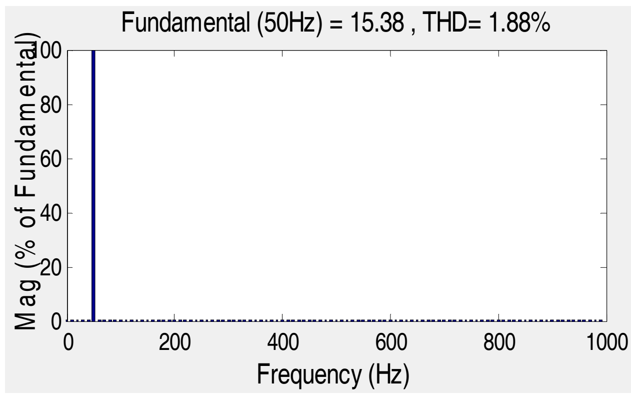

Fig. 12 – Total harmonic distortion.

The dc bus voltage steady state value is reached in a relatively short time with negligible ripple oscillation in steady state, as is depicted in Fig. 6. The grid voltage and current are shown in Figs. 7 and 9 respectively, where it can be observed that both variables are synchronized and the power factor is close to unity. The zoom of grid voltage and current are shown in Fig. 8 and 10 respectively. The grid phase current, waveforms are sinusoidal with a total harmonic distortion (THD) around 1.88 %, which confirms that line current has been acceptable. The value of the THD is presented in Fig 12. Figure 11 represents the active and reactive power to the grid. The active and reactive powers of the grid are decoupled and are perfectly tracking their desired references. Note that the reactive power tends toward zero.

8. **CONCLUSION**

The study presented in this article applies generally, the optimization of a grid-connected photovoltaic system performance. For this, we have used the control modern techniques based on fuzzy logic control and direct power control. Simulation results show that, the proposed system improves the performance of the grid-connected photovoltaic power system. The MPPT control gives a quick response reduced power oscillations around the optimal point and is more effective than the conventional developed control devices. The inverter has been controlled by direct power control. This method actually gives a good response. Finally, simulation results show a very good performance of the proposed system.

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